DOUBLE PULSE EXPERIMENT WITH A VELVET CATHODE ON THE ATA INJECTOR*

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Double pulse transport experiments were conducted on the front end of the ATA accelerator to obtain data on the capability of a velvet cloth cathode to produce two successive pulses. Pulses of approximately 3 kA were extracted from the cathode with interpulse spacings varying from 150 ns to 2.8 μs using an anode-cathode voltage of about 1 MV. Analysis of the current and voltage waveform data from the injector indicate that the effects of cathode plasma on the second pulse of a two-pulse burst is minimal.

I. BACKGROUND

The ATA injector has typically used velvet cathodes [1] to obtain its 10 kA operation at 2.5 MV. Although the precise mechanism by which these cathodes operate is uncertain, it is believed that there is field emission from the tips of velvet fibers that extend into the gap. The emitted current is believed to lead to the creation of a plasma layer at the cathode surface. Velvet cathodes have been used occasionally at ATA for short bursts at repetition rates up to 1 kHz. Velvet sources were employed for a short time on another high repetition rate injector. Above a 50 Hz rate the emission current would die out, but recover as the repetition rate was lowered. This suggested that the source of the plasma from which the electrons were extracted might be adsorbed gasses on the fiber's surface which were totally depleted above a certain repetition rate. The rate of deposition of gas onto a clean surface is proportional to the pressure, and there is an equilibrium thickness of adsorbed gasses on a surface for a given ambient pressure.

These inferences suggest that there might be a suitably large amount of adsorbed gasses on the velvet surface to permit multiple-pulse operation.

II. INJECTOR CONFIGURATION

A schematic of the injector used in the Double Pulse Experiments is presented in Fig. 1. The ATA injector is composed of two sections, each with five 250-kV induction cells in series, that in normal operation provides a nominal 2.5-MV, 70-ns FWHM pulse across the anode-cathode (A-K) gap. During the experiments a 5.25-inch diameter velvet cathode was used as the electron source. The separation between the anode and the cathode was about 14 cm during most of the experiment. At an anode-cathode voltage, V_{ak}, of about 2.5 MV (normal operation) approximately 8 kA of current is drawn from the cathode. At $V_{ak} \approx 1.0$ MV, as used in the double pulse experiments, approximately 2.5 kA of current is drawn from the cathode. The average emission current density to provide 2.5 kA of current from a 5.25 inch cathode is 18 A/cm^2.

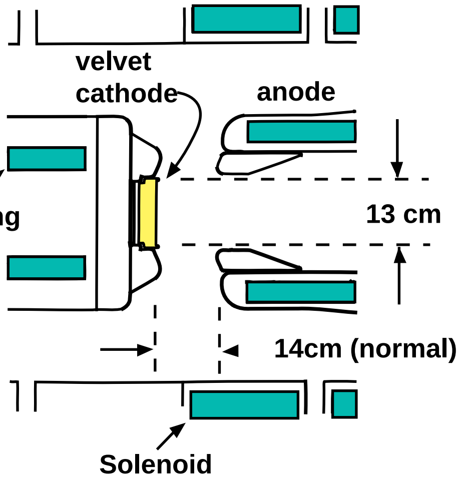

Figure 1. Electrode configuration used for double pulse experiment.

III. DOUBLE PULSE OPERATION

For these experiments the triggering arrangement of the ATA injector was modified so that the even and odd cells of the injector could be fired independently. Extra lengths of cable were added to the high voltage trigger of the odd cells so their firing could be delayed in fixed increments. Since for each pulse only half the cells were involved, the anode-cathode voltage was about half of its normal value. The electrode package was not modified for the reduce voltage operation. We expect that the beam brightness would decrease for the lower voltage operation. When the A-K gap was shortened by about 3 cm in the latter part of the experiment, there was a further decrease in the beam brightness.

Figure 2 shows data for a 2.2 μs time separation between the first and second shot. It also shows a source of error involved with trying to determine changes between

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the two pulses. If the two pulses are captured on the same oscilloscope, the amplitude resolution is not good. If the data is captured on two oscilloscopes, care must be take to ensure the calibrations are identical to permit detection of small differences between the two traces. The voltage of the second pulse could be adjusted independently of the first pulse.

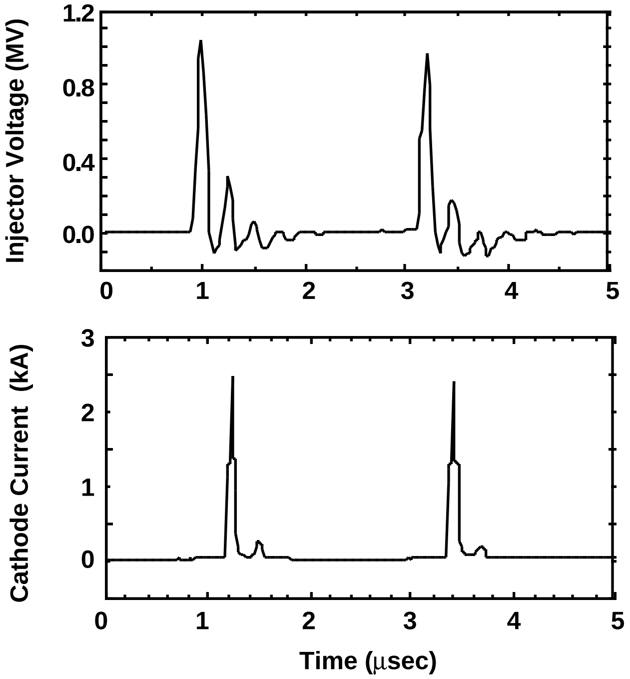

Figure 2. Example of waveforms for a double pulse. There is a small time shift between the two graphs. Current is only emitted on the positive part of voltage pulse.

A. Effective gap closure

The emission current density, J_o, that will be drawn across an infinite diode with separation d_o, and voltage V_o is given for the steady-state non-relativistic case by:

$$J_o = \chi \frac{V_o^{3/2}}{(d_o)^2}$$

where $\chi = \frac{4\,\varepsilon_o}{9}\left(\frac{2e}{m}\right)^{1/2}$. For our experiments we define an effective gap, d_g, such that:

$$J_c = \chi \frac{V_{ak}^{3/2}}{(d_g)^2}$$

where J_c is the average cathode current density. During the experiments d_g was about 12 cm. We were looking at gap closure, or a change in d_g, of about 1% d_g between the first and second pulse. Figure 3 shows a collection of data on this change in the effective gap between the first and second pulse. As plasma drifts into the gap from the cathode surface after the first shot, the value of d_g will decrease. If the active emission area of the cathode increases between the two pulses, d_g will also be reduced.

B. Reduced AK gap experiments

The first group of experiments was performed with d_g =12 cm. For these setting $J_c \approx 18$ A/cm^2. We wished to know if the plasma closure problem would be more severe at higher J_c, so in the latter experiments we shorten d_g to about 10 cm. This gap spacing increased J_c to about 27 A/cm^2. The change in the effects of the surface plasma on the second pulse between d_g=12 cm and d_g=10 cm was smaller that our ability to resolve. In the later experiments we were able to transport 3.2 kA through a 12-m transport section, and focus the beam to a small radius on the beam dump.

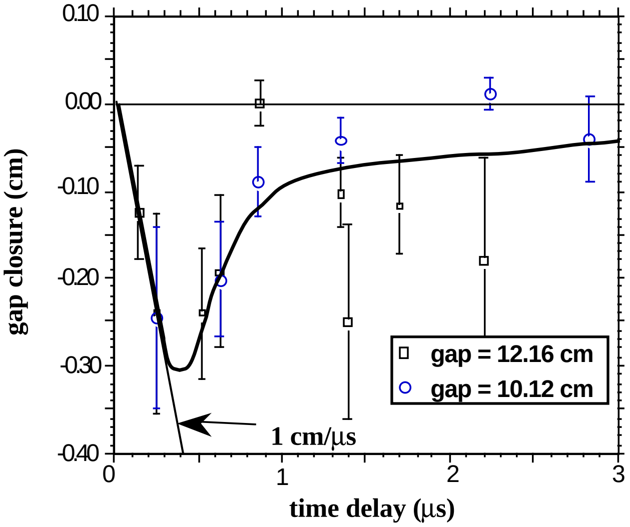

Figure 3. Changes of d_g between the first and second pulse as function of time delay.

For a long pulse we would expect[1,2] the gap to close at rate of 1-3 cm/µs. The first pulse is about 70 ns long. The gap does seem to close at about 1 cm/µs rate for the first few hundred nanoseconds. After about 400 ns the effect of the cathode surface plasma on the second pulse is weakened implying that the plasma is tenuous. There is considerable scatter in data after this time. However, the effect on the second pulse is small, and somewhat masked by calibration problems. Following a pulse there is considerable “ringing” on the cell voltage from the mismatched impedance at the lower voltage operation (as shown in Fig. 2). Thus it is difficult to obtain flat waveshapes on the second pulse at short delay times.

C. Emittance variation

Although the injector may have the same perveance for the two pulses, it is important that the beam quality of the second pulse is not degraded. Analysis of the current and voltage waveform data from the injector indicate that there is no large emittance change between the two pulses for the core of the beam. For the first set of experiments there was a 1-m-long 2-cm-diameter collimator immersed in a magnetic field in the beamline after the injector. This section is normally used to select the inner core of the beam's phase space for downstream experiments, and is called the emittance selector. In the first set of experiments it selected about 10% of the beam, which was then transported through a 8-m transport section to the beam dump (current at dump is shown in Fig. 4). Small energy variations can explain the differences between the two sets shown in Fig. 4. The vertical and horizontal position were also shown to have similar waveshapes for the first and second pulse. From this we believe that the core beam emittance is about the same for the two pulses.

Latter experiments in which most of the current (with no emittance collimator in the system about 3.2 kA of current was transported to the dump) also indicate that the change in emittance between the first and second pulse is small. However, in these experiments the magnetic field was not zeroed on the cathode. The injector electrodes would need to be rebuilt for a good determination of the emittance variation between the first and second pulses.

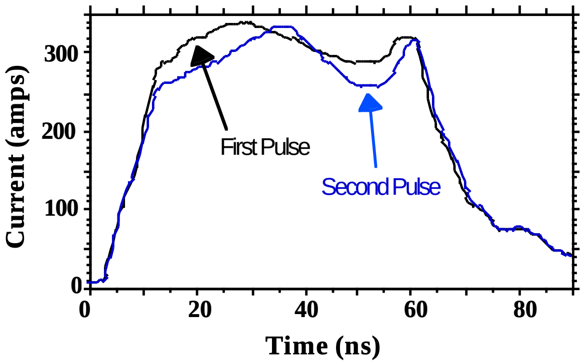

Figure 4. Beam current after collimator and a 8-m transport section. Each pulse is an average of six pulses.

IV. PLASMA DENSITIES

The data shown in Fig. 3 suggests that the plasma becomes too tenuous to support emission from its boundary at about 400-500 ns after the first pulse. Initially, the inferred plasma velocity is approximately 1 cm/μs with a density sufficiently high that some point on its boundary can act as an effective emitting surface. As the plasma expands into the A-K gap its density drops until it can no longer sustain emission from its surface and the effective emitting surface retreats towards the physical surface of the velvet. We may roughly estimate this critical density by calculating the electron density required to provide the average current density J_c. We may estimate the electron energy at a distance d from the velvet by using the non-relativistic expression for the Child-Langmuir solution:

$$V = V_{ak}\left(\frac{\Delta}{d_g}\right)^{4/3}.$$

where d_g is the effective A-K gap distance and V_{ak} is the anode-cathode potential. From Fig. 3, after the plasma had propagated about 0.3 cm into the gap the cathode emission density started to drop. Using d_g as 12 cm and Δ as 0.3 cm for a 1 MV anode potential yields an energy of 7.3 KeV. A current density of 18 A/cm^2 then requires an electron density $n \approx 2\text{x}10^{10}$ cm^{-3}. If the ion density is equal to or greater than this value then the effective emitting surface is located at distance Δ. from the cathode surface. However, if the plasma density is less than this value then the effective emitting surface shifts back towards the cathode.

V. CONCLUSIONS

The experiments clearly show that a velvet cathode is capable of producing two pulses at 20-30 A/cm^2 at interpulse spacings from 150 ns to 3 μs. For a long pulse machine we would expect that the anode-cathode gap would continue to close at order of 1 cm/μs. However, for a short pulse injector the plasma effects from the first pulse decrease after about 400 ns. Analysis of the current and voltage waveform data from the injector indicates that the effects of cathode plasma on the second pulse of a two pulse burst is minimal.

VI. ACKNOWLEDGEMENTS

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VII. REFERENCES

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